Appendix B
Commonly Used Computer Models for Corps Flood Damage Reduction Studies

B-1. Introduction

This appendix describes Corps-developed computer models that are used commonly in flood damage reduction planning studies. These models simulate critical processes and provide information necessary to evaluate the economic objective function and to confirm satisfaction of the environmental-protection and performance constraints.

a. Definitions. For clarity, the description herein makes a distinction between mathematical models, computer models (also called programs), and applications. A mathematical model is a symbolic representation of the behavior of a system. For example, the combination of the continuity and momentum equations is a mathematical model of flow in an open channel. To yield information, the equations of a mathematical model must be solved. If the equations are relatively simple, they may be solved with pencil and paper and electronic calculator. For example, the equations of the unit-hydrograph model can be solved in this fashion to predict runoff from a simple rainstorm. On the other hand, if the equations included in the model are too numerous or too complex to solve with pencil, paper, and calculator, they may be solved instead by translating the equations and an appropriate equation solver into computer code. The result is a computer model or computer program. When the equations of a mathematical model are solved with site-specific initial and boundary conditions and parameters, the model simulates the processes and predicts what will happen to the particular system. This solution with specified conditions is an application of the model. An application may use a computer model, or it may use the mathematical model with solution with pencil, paper, and calculator.

b. Selecting a model. Ford and Davis (1989) write that water-resources planning and management is similar to home improvement: In both, the appropriate tool must be selected to solve the problems at hand. In the case of home improvement, the decision is what hand tool to use: Should it be a hand saw or a chain saw? In the case of water management, the decision is what computer tool or model to use. Jackson (1982) suggests that to select the best model, one should follow the procedure illustrated by Figure B-1. In the case of flood damage reduction planning, the information identified in step 1 of this procedure typically includes:

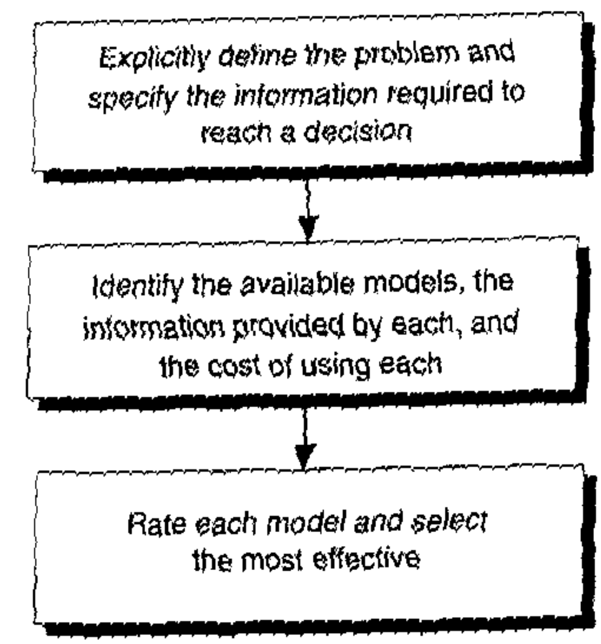

Figure B-1. Steps in selecting the appropriate model

- Stream-discharge time series or peaks.
- Volume time series or totals.
- River or reservoir water depth time series or maximums.
- Probabilities (frequencies) of extreme discharge, volume, or depth magnitudes.
- Inundated-area geometry.
- Landform changes due to erosion or deposition; or
- Economic, social, or environmental costs and benefits associated with any of these items.

The remainder of this appendix is devoted to step 2: identifying available models that can provide this information.

c. Classification of the computer models. The information provided by a computer model is correlated directly with the processes modeled. For flood damage reduction planning, the critical processes include those shown in Table B-1. Some computer models focus not on the processes but on system accomplishments, so accomplishment models are included in this appendix as an additional classification. Accomplishment models may simulate critical processes as a secondary function, but their primary function is to use information from such a simulation to evaluate economic, social, or environmental benefits and costs.

d. A warning.

(1) Scott McNeally, chairman of a Sun Microsystems, suggested that "... the shelf life of biscuits and technology is about the same (NY Times, 27 March 1993)." Accordingly, the hydrologic engineer is cautioned that the state-of-practice in computer modeling changes rapidly. He or she should consult HQUSACE, WES, and HEC staff for information on computer model updates or new computer models before selecting for application one of the models described in this appendix.

(2) In unusual circumstances, the computer models described herein will not provide the information required. In those cases, the hydrologic engineer may refer to theses and dissertations, project reports, and technical journals (including AGU's Water Resources Research, ASCE's Journal of Hydraulic Engineering, ASCE's Journal of Water Resources Planning and Management, and AWRA's Water Resources Bulletin) to identify an appropriate tool. DeVries and Hromadka (1993), Renard, Rawls, and Fogel (1982), Larson et al. (1982), and WMO (1975) have published reviews that may be helpful.

B-2. Runoff-Process Models

a. HEC-1. HEC-1 is a single-event model that estimates runoff from precipitation with a spatially and temporally lumped description of a catchment (USACE 1990b). HEC-1 incorporates a variety of conceptual or quasi-conceptual mathematical models; the user specifies through input which of these are used. Parameters for the various mathematical models also are specified by user input. HEC-1 includes a parameter estimation routine that will estimate most runoff model parameters if proper hydrometeorological data are available. HEC-1 provides stream-discharge time series and peaks, and volume totals for decision making.

Table B-1
Critical Processes to Model for Flood Damage Reduction Planning

Process	Description
Catchment-runoff	These are the processes that govern how precipitation that falls on a catchment runs off that catchment. Runoff processes include evaporation, transpiration, infiltration, percolation, interflow, overland flow, and baseflow. Modeling these processes provides information on stream-discharge time series or peaks, and volume time series or totals.
Fluvial	These are the processes that govern fluid flow in an open channel when that fluid is subjected to external forces. Modeling these processes provides information on river or reservoir depth time series or maximums, and inundated-area geometry.
Alluvial	These are the processes that govern the erosion and deposition of sediment due to flow in an open channel. Modeling these processes provides information on landform changes due to erosion or deposition, river or reservoir water depth time series or maximums, and inundated-area geometry.
Pressure-flow	These are the processes that govern how water flows under pressure in closed conduits. For water excess management in urban settings, these processes are often planned to function as pressure conduits for the design flow or greater events (ASCE/WEF 1992).
Statistical	Physical, chemical, or biological processes exhibit randomness and variability that cannot be accounted for with models of the behavior of a system. Models of statistical processes recognize this and seek to describe the randomness and variability by establishing an empirical relationship between probability and magnitude. A statistical-process model yields information on probabilities associated with extreme discharge, volume, or depth magnitudes.

(1) Mathematical models included in the computer model. The runoff process, as represented in HEC-1, is illustrated by Figure B-2. The mathematical models incorporated in this representation include those shown in Table B-2. In addition to runoff process models, HEC-1 includes the following fluvial process models for routing hydrographs: Muskingum, kinematic wave, modified Puls (level pool), and Muskingum-Cunge. The user may select any one appropriate for a given stream reach. As with other mathematical models included in HEC-1, any combination of these may be used. Parameters are defined with user input.

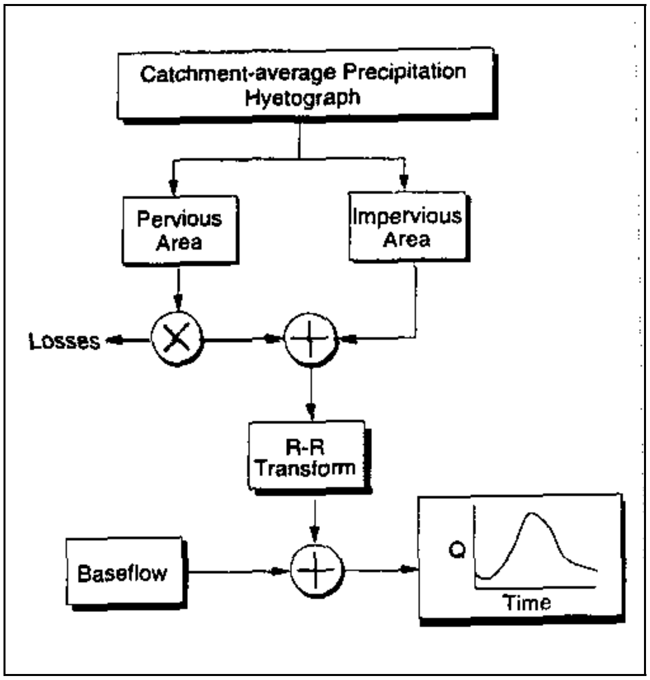

Figure B-2. HEC-1 representation of runoff process

(2) Complex catchment representation. With the runoff and fluvial process models used in combination, large catchments in which parameters or precipitation vary spatially can be analyzed. To do so, the catchment is subdivided, the runoff-process models are used to compute runoff at various locations, and the routing models are used to account for flow in stream channels to common points. Figure B-3 illustrates this approach. First runoff is computed for subcatchment 1 with the runoff process models. The resulting hydrograph represents the flow at control point A. This hydrograph is routed from A to B with a fluvial process model. The hydrograph of runoff from subcatchment 2 is computed and added to the routed hydrograph. This yields an estimate of total runoff, accounting for spatial variation in rainfall and catchment characteristics.

(3) Input and output. To estimate catchment runoff with HEC-1, the user must provide the input shown in Table B-3. Output from HEC-1 includes the following: A summary report of the user's input; for each

Table B-2
Mathematical Models Included in HEC-1

Model Type	Description
Loss	To account for infiltration, depression storage, and other reductions in volume of precipitation on pervious areas in a catchment, HEC-1 offers the following alternatives: initial loss plus uniform rate; SCS curve number; 4-parameter exponential; Holtan's; and Green and Ampt. The user may select any one of these for a catchment. For complex catchments that are subdivided for analysis, the user can select combinations of the loss models.
Snowfall and snowmelt	These models simulate snowfall formation and accumulation and estimate runoff volumes due to snowmelt. The snowfall model permits division of a catchment into elevation zones. The user specifies a time series of temperatures for the lowest, and the model estimates temperatures for all others with a lapse rate. Precipitation is assumed to fall as snow if the zone temperature is less than a user-defined freezing threshold. Melt occurs when the temperature exceeds a user-defined melting threshold. Snowfall is added to and snowmelt is subtracted from the snowpack in each zone. Snowmelt may be computed with either a degree-day model or an energy-budget model.
Runoff transform	Runoff volumes may be transformed to runoff hydrographs in program HEC-1 with either a unit hydrograph model or via solution of the kinematic-wave simplification of the St. Venant equations.
Baseflow	HEC-1 incorporates a single model of baseflow, which is based on the assumption that drainage of water added to storage in a catchment can be modeled well as exponential decay.

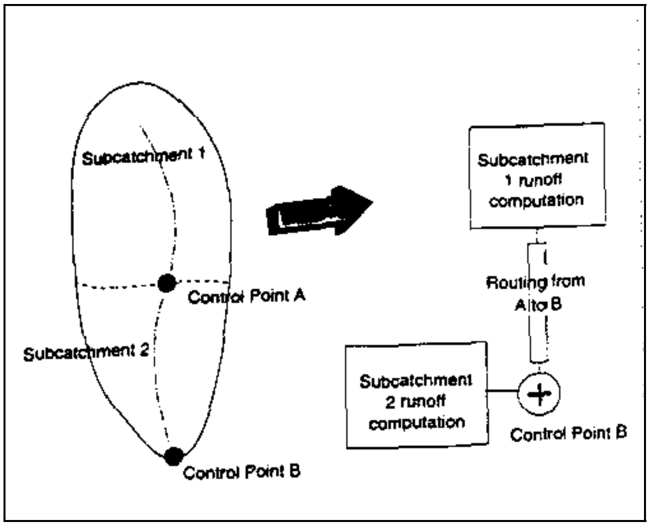

Figure B-3. Illustration of complex catchment modeling by subdivision

subcatchment, a report of the average-precipitation depth, the loss, and the excess for each simulation step, plus a report showing the computed runoff hydrograph ordinates; for each stream reach modeled, a report of the outflow (downstream) hydrograph ordinates; and various summary output tables that show the discharge peaks and times of peak at system control points.

(4) Utility programs. HEC has developed utility programs that simplify use of HEC-1; two are summarized in Table B-4.

B-3. Fluvial-Process Models

a. HEC-2. HEC-2 solves the equations of one-dimensional, steady, gradually varied flow to predict water-surface elevation along a natural or constructed open channel (USACE 1982a). Water-surface profiles in either subcritical or supercritical regime can be computed. HEC-2 also incorporates conceptual and empirical models that allow analysis necessary for common designing, planning, and regulating problems. These special capabilities are summarized in Table B-5.

(1) Mathematical models included.

(a) Given a complete description of the geometric boundaries which contain the flow in an open channel, HEC-2 estimates the average flow depth and velocity in the prescribed cross sections by solving the one-dimensional energy equation. This formulation assumes that flow is steady and gradually varied, with localized rapidly varied flow, such as at weirs or culvert inlets; flow is turbulent, and fully rough, with viscous forces playing a minor role; flow is homogeneous, with constant fluid density throughout the flow field; flow can be adequately characterized by movement in a single direction; and pressure distribution at a cross section is hydrostatic. Violation of one or more of these assumptions does not necessarily mean that results of analysis with HEC-2 are wrong. Instead, the relative effect of these assumptions upon the results of a particular application must be evaluated.

Table B-3
HEC-1 Input

Input Item	Description
Precipitation	The precipitation may be provided as catchment average depth or as depths observed at gages. The user must provide a temporal distribution of precipitation: this may be the historical observation at a gage, or it may be a design-storm distribution.
Catchment and channel physical characteristics, including characteristics of water-control facilities	The user must delineate catchment boundaries and define, via input, the catchment area. If the catchment is subdivided for analysis, the user must define, through the sequence of input, how the system is schematized for modeling. If the stream system includes water-control facilities, such as detention ponds, the characteristics of these must be specified also.
Model parameters	User must specify all appropriate loss-model, runoff transform model, baseflow model, and routing model parameters.
Simulation specification	User must specify the time step and duration of the simulation, subject to constraints imposed by the available computer memory.

Table B-4
Utility Programs for and Specialized Versions of HEC-1

Program	Description
HEC-DSS (USACE 1990a, 1991)	This is a time-series database management system (DBMS). It creates specially formatted random-access files, with a hierarchical system of record names to expedite storage and retrieval of data in the files. Data in the DBMS may be accessed through a set of front-end utility programs that permit data entry, reporting, charting, and database housekeeping. Further, the data can be accessed via a FORTRAN library of routines that read, write, and otherwise interact with database files. It is through this library that HEC-1 (and many other models from HEC) retrieves data from and files data in the database.
HMR-52 (USACE 1984)	This program computes catchment-average precipitation for probable maximum design storms (PMS), using criteria established by the National Weather Service (NWS) for catchments east of the 103rd meridian in the United States. The storm may be used, in turn, as input to HEC-1 to estimate the probable maximum flood (PMF) runoff. This extreme discharge is the basis for dam-safety analysis.

Table B-5
Special Capabilities of HEC-2

Capability	Description
Treatment of effective flow areas	Several options are available to restrict flow to certain portions of a given cross section. This is often required because of sediment deposits, floodplain encroachments, oxbow lakes, etc.
Analysis of bridge and culvert losses	The energy loss due to bridge piers and culverts can be estimated.
Analysis of channel	Six methods of specifying floodplain encroachments are available. The equal conveyance reduction method is used to determine the floodway boundaries for a flood insurance study.
Evaluation of channel improvement	Natural river cross-section data may be modified simply with the channel improvement option. This allows simulation of the effects of excavating a compound trapezoidal channel section into the natural section.
Calibration of high water marks	When high water marks are known for a specified discharge, HEC-2 can estimate the effective Manning's *n* value necessary to reproduce this observed elevation.
Development of storage-outflow function	HEC-2 includes the capability to develop a storage volume versus relationship for a river reach. This can, in turn, be used for streamflow routing with the modified Puls and other simple fluvial process models.
Analysis of split flow	For flow splits (such as at diversion structures, levee overtoppings, etc.) HEC-2 balances the energy grade line elevations at the split and downstream confluence. Weir flow, normal depth, or a diversion rating curve may describe the hydraulics of the split.
Simulation of flow in ice-covered streams	Water-surface profiles with a stationary, floating ice cover can be estimated. The user must provide the thickness and effective n value of the ice cover.

(b) HEC-2 estimates the total energy loss between two adjacent sections as the sum of frictional energy loss due to channel roughness; form-energy loss due to expansion and contraction; and energy loss due to flow through structures, such as a bridges, culverts, or weirs. The frictional energy loss is the product of the average energy grade line slope and the distance between cross sections. This energy grade line slope at a section is computed with Manning's equation. Several schemes are available in HEC-2 for determining the average energy grade line slope between two cross sections: arithmetic, geometric, or harmonic mean energy slope at adjacent cross sections, or the average conveyance at adjacent cross sections. HEC-2 includes a contraction/expansion energy loss model that estimates that loss as a function of the difference in velocity head between two cross sections.

(c) By computing the energy loss between a river cross section with a known water-surface elevation and an adjacent cross section, the water-surface elevation at the adjacent section can be determined. For subcritical flow, the computations start with a known relationship between discharge and water-surface elevation at the downstream boundary of the fluvial system and proceed in an upstream direction until the water-surface elevation is computed at each cross section. For supercritical flow, the computations start with a known water-surface elevation at the upstream boundary and proceed in a downstream direction.

(2) Input and output. HEC-2 is a generalized computer program. The user must therefore provide all stream characteristics and boundary conditions via input. For a simple application, the input requirements are as shown in Table B-6. A variety of output data may be selected by the user, including a report of computed water-surface elevation, velocity, and other pertinent characteristics of flow at each channel cross section. HEC-2 will prepare an electronic file with the computed results for subsequent access by graphing and reporting utilities.

b. UNET. Program UNET simulates one-dimensional, unsteady flow through either a simple open channel, a dendritic system of open channels, or a network of open channels (Barkau 1985, USACE 1993b). This permits analysis of diversions and confluences in a looped system, including systems in which the direction of flow may reverse. UNET has the capability to model also flow in lakes, bridges, culverts, weirs, and gated spillways, using mathematical models that are essentially the same as those included in HEC-2.

(1) Mathematical models included. UNET solves a linearized finite-difference approximation of the full one-dimensional, unsteady flow equations (Barkau 1985). The solution algorithm uses sparse matrix techniques with Gaussian reduction.

(2) Input requirements and output. The input required for UNET is similar to that required for HEC-2. Additional input is required to describe the interconnection of stream segments, and location of lakes and storage elements. UNET uses the HEC-DSS described in Table B-4 to store boundary conditions, such as rating curves and hydrographs. Table B-7 defines UNET input requirements. Unsteady flow models typically produce large reports of computational results, and UNET is not

Table B-6
Input Required for HEC-2

Input Item	Description
Flow regime	The user must assess the location of normal depth relative to critical depth for each application. For a subcritical flow regime, cross-section data are specified progressing upstream. For supercritical flow regime, data are specified progressing downstream. For unknown or mixed regimes, multiple input data sets are prepared and results combined, as discussed in the HEC-2 user's manual.
Starting boundary condition	HEC-2 solves the one-dimensional energy equation for a given stream state, so the starting water-surface elevation must be specified. This can be input directly or estimated by the program.
Discharge	The steady flow discharge must be specified for each stream segment. This may change along the profile in order to include effects of tributaries, diversions, etc.
Energy loss coefficients	For a basic application of HEC-2, user must specify Manning's *n* for the main channel, left and right overbanks. User may specify contraction and expansion loss coefficients.
Cross-section geometry	Boundary geometry for the analysis is provided by a series of elevation versus station coordinate points at each cross section. Cross sections are required at representative locations throughout the reach, but especially where slope, conveyance, or roughness change significantly.
Reach length	The distance between cross sections must be specified to permit computation of the turbulent energy loss due to boundary roughness. HEC-2 allows input of separate reach lengths for the main channel, left and right overbanks to describe curved channels, river meanders, etc.

an exception. The model computes and reports depths, velocities, and other pertinent flow characteristics at each cross section for each time step of the finite-difference solution of the flow equations. These results may be filed with the HEC-DSS and subsequently plotted with DSPLAY, the graphing program of the database management system.

c. HIVEL2D Program.

(1) HIVEL2D solves the two-dimensional, depth-averaged, unsteady flow equations for high velocity flow in a channel. This computer program is specifically designed to evaluate flow behavior at bridge piers, transitions, confluences, curves, etc. in lined flood control channels where the dominant flow regime is supercritical. The program can also be used for subcritical flow situations that may transition into or out of supercritical flow. Due to the way the differential equations of flow are formulated and solved, HIVEL2D can accurately capture the effects of shocks. Assumptions in the mathematical model include the following: The pressure distribution is hydrostatic; the coriolis, buoyancy, and wind resistance effects are insignificant; and vertical accelerations are unimportant. These assumptions are typically valid for most channels with slopes flatter than 0.05. At present the mathematical model does include third order Boussinesque terms which describe shorter waves such as those caused by reflection off of a channel wall. This means that guidance in EM 1110-2-1601 and possibly physical modeling efforts should accompany an application of HIVEL2D.

(2) For the Los Angeles River, HIVEL2D was successfully applied in conjunction with physical modeling efforts in order to evaluate the ability of existing bridges to pass the design flow and to determine the effects of proposed bridge modifications. Table B-8 describes the general capabilities of the model, and Table B-9 describes the input requirements.

B-4. Alluvial-Process Models

a. HEC-6. HEC-6 models the effects of river sediment transport and resulting changes in the flow boundaries with a one-dimensional representation of the open-channel flow (USACE 1993b). The program computes changes in riverbed profiles for a single flood event or for a long-term sequence of flows. HEC-6 provides information on depths and landform changes due to erosion or deposition. Thus it can be used to evaluate the movement of a stream.

(1) Mathematical models included.

(a) HEC-6 solves the one-dimensional energy equation using a computation technique similar to that included in computer model HEC-2. HEC-6 does not include the empirical models for bridge and culvert energy losses, but it does allow for the specification of an internal elevation-discharge boundary condition, the development of which can be accomplished using HEC-2. Transport calculations are made for a control volume defined using the cross-section locations and an assumed

Table B-7
Input Requirements for UNET

Input Item	Description
Channel geometry	Each cross section is input in HEC-2 format. The cross-section file is arranged in a reach-by-reach order with the upstream and downstream connectivity specified. This allows changes to be made without reordering the entire data file.
Boundary conditions	Discharge hydrographs or water-surface elevation rating curves must be specified for each terminal reach boundary.
Initial conditions	The initial depth and velocity must be specified for each cross section. The model has the ability to save the final results of one application to be used as the initial conditions file for another application.
Channel roughness	A value of Manning's *n* is required for each cross section. Contraction and expansion coefficients and weir coefficient may also be specified.

Table B-8
Special Capabilities of HIVEL2D

Input Item	Description
Flow regime	Both supercritical and subcritical flow as well as the associated horizontal accelerations or shocks can be simulated.
Channel geometry	The solution uses both triangular and quadrilateral finite elements, thus allowing complex geometries to be simulated. A special formulation of the solution technique allows the simulation of sloped channel sidewalls.
Energy losses	A value of Manning's *n* can be specified for each element in the computational grid. The model has the ability to compute the turbulent eddy coefficients based on local hydraulic properties and bed roughness.
Output format	The program can be used with standard graphical interfaces such as TABS-II in order to view plots of computed depth and velocity.

Table B-9
Input Requirements for HIVEL2D

Input Item	Description
Channel geometry	Each node of the finite element grid requires the specification of both x and y horizontal coordinates, and the elevation of the bed of the channel. The node connectivity list for each element is also required. The model has the ability to create the finite element grid by the specification of centerline bearings, wall offsets, curvature radii, etc.
Boundary conditions	Depth and/or discharge boundary conditions must be specified. For unsteady flow applications, a hydrograph and/or rating curve is used.
Initial conditions	The initial depth and velocity must be specified at each computational node in the solution network. The model has the ability to save the final results of one application to be used as the initial conditions file for another application.
Channel roughness	A value of Manning's *n* is required for each element of the computational grid.

depth of alluvial deposits. The computed energy slope, depth, velocity, and shear stress at each cross section are used to compute the sediment transport capacity at each cross section. These rates, along with sediment supply rate and armoring potential, are used for volumetric accounting of sediment movement through the system. The amount of scour or deposition is computed by dividing the surface area of the mobile boundary into the change in sediment volume. A new water-surface profile is then computed for the updated channel geometry.

(b) Sediment transport rates in HEC-6 are computed for 20 different grain size categories ranging from clay (less than 0.004 mm) through silt (less than 0.063 mm) up to large boulders (2,048 mm). A variety of sediment transport equations, based on either cohesive or noncohesive theory, can be selected for the transport capacity calculations. Mathematical models of incipient motion, channel bed armoring, grain size sorting, and particle entrainment are also included in HEC-6.

(c) To account for unsteady flow with HEC-6, a hydrograph is discretized into a series of steady flows, and a water-surface profile is computed using a standard step backwater approach. This procedure is repeated until the entire event has been simulated.

(d) Due to the one-dimensional formulation, HEC-6 does not represent the multi-dimensional nature of sandbar formation, secondary flow currents, and streambank failure.

(2) Input and output. HEC-6 requires all of the information necessary for a one-dimensional fluvial

model, including a complete description of the geometric boundaries of the channel that contains the flow, definition of the flow regime, and specification of energy loss coefficients. In addition, the user must develop and provide information on sediment grain-size distribution; sediment specific gravity, shape factor, unit weight, and fall velocity; and boundary conditions. HEC-6 output includes reports of both hydraulic and sediment-transport calculations. The basic level of output data includes a report of initial conditions, hydraulic calculations, sediment transport calculations, accumulated sediment volumes, and overall bed elevation changes.

b. TABS-2. TABS-2 is a collection of generalized computer programs and utility codes integrated into a numerical modeling system for studying two-dimensional hydraulics, transport, and sedimentation processes in rivers, reservoirs, bays, and estuaries (EM 1110-2-1416, Thomas and McAnally 1985). Figure B-4 illustrates the interaction of the components of TABS-2.

(1) Mathematical models included. TABS-2 solves the two-dimensional, depth-averaged momentum and continuity equations, for either steady or unsteady flow. TABS-2 uses a finite element technique and computes, for each node of the finite-element representation, flow depth and longitudinal and lateral velocities. The sedimentation component of the model then computes the transport capacity using the two-dimensional convection-diffusion equation with bed source terms. The actual transport is based on sediment availability. TABS-2 can handle both cohesive and noncohesive sediment transport.

(2) Input and output. The user must define the finite-element grid. In addition to the grid network data, the user must provide information on initial bed material sizes for each element. As with the other alluvial process models, the inflowing sediment load and hydrograph must be specified by the user. TABS-2 will provide detailed reports of all computations. To aid the user in digesting this mass of output, TABS-2 includes also a postprocessor that displays the results of computations graphically. This graphical output includes velocity vector plots, contour plots of scour/deposit depths, and shear stress variations.

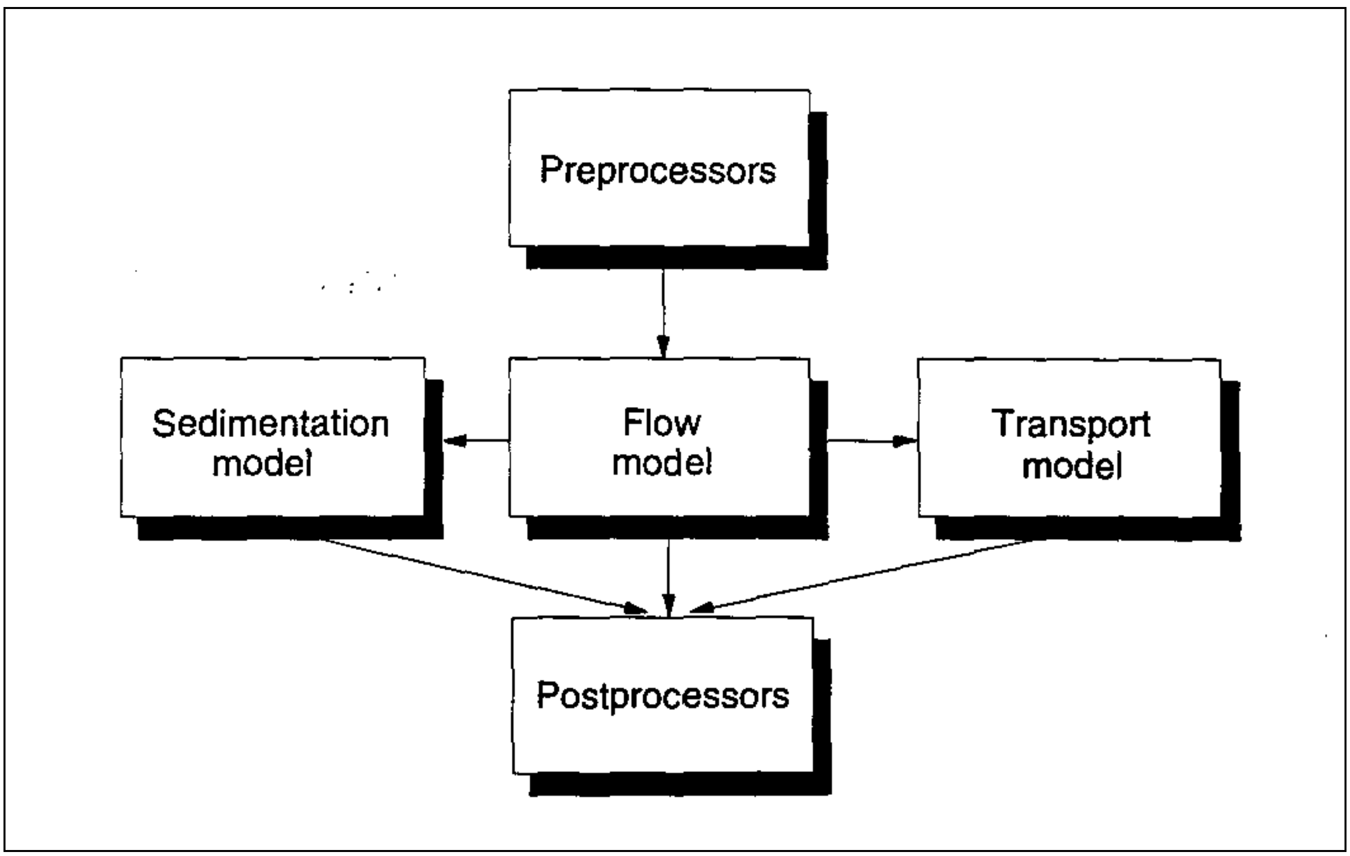

Figure B-4. Components of TABS-2

c. SAM. The SAM program, entitled Hydraulic Design Package for Flood Control Channels, was developed to provide guidance on the width, depth, and slope of stable channels in alluvial materials. The mathematical model includes one-dimensional, steady flow hydraulic calculations, sediment transport capacity calculations, and sediment yield calculations based on flow duration. SAM is, in a sense, a scaled back version of HEC-6. It does have additional capabilities, however, and these are listed in Table B-10. The input is largely interactive. SAM also has the ability to read TAPE95 output files from HEC-2 in order to retrieve hydraulic properties.

B-5. Statistical-Process Computer Models

HEC-FA. In the United States, a number of Federal agencies conduct annual maximum discharge frequency analysis for decision making. Until 1967, each agency established its own methods and procedures for the analysis, leading to occasional differences in estimates of quantiles or probabilities. To promote a consistent approach, a multi-agency committee of the USWRC studied alternatives and recommended the log-Pearson type III distribution for use by U.S. Federal agencies (Interagency Advisory Committee 1982). The committee recommended also procedures for treating small samples, outliers, zero flows, broken and incomplete records, and historical flood information. Program HEC-FA (USACE 1992a) implements these guidelines.

a. Mathematical models included. HEC-FA fits a Pearson type III statistical model (distribution) to logarithms of an observed flood series, using modified method-of-moments parameter estimators. In simple terms, this statistical model estimates the discharge that is exceeded with specified probability. Table B-11 shows the analysis procedures used by the model in fitting the distribution. The Interagency Advisory Committee guidelines (also known as Bulletin 17B) and EM 1110-2-1415 describe the procedures in more detail.

(2) Input requirements and output. HEC-FA provides information on probabilities (frequencies) of extreme discharge magnitudes. To do so, it requires the input shown in Table B-12. Output from HEC-FA includes a summary report of the user's input; computed sample statistics and estimated model parameters; a report of the computed frequency function, showing selected quantiles; and plots of the frequency function.

B-6. Accomplishment Models

The computer models described earlier provide information on system behavior; they simulate processes by which a system input is transformed to a system output. But for informed damage-reduction planning, the hydrologic engineer must provide information on system accomplishment: the consequence of a particular system output or a particular state of the system. Several of the models described include the capability to assess accomplishment. For example, HEC-1 includes routines to model detention-structure accomplishment, given hydrographs computed with the runoff process models it includes. But for more detailed analysis, computer models designed especially for evaluation are available. Three are described here: EAD, a flood-damage evaluation model; HEC-5, a reservoir-system evaluation model; and HEC-IFH, an interior-area-protection evaluation model.

Table B-10
Special Capabilities of SAM

Input Item	Description
Stable channel design	SAM has the ability to predict stable channel dimensions including width, depth, and slope, for a given discharge.
Sediment transport	A wide range of sediment transport equations can be selected. SAM has the ability to produce sediment transport versus discharge curves for a number of different transport functions in a single execution.
Sediment yield	SAM can compute average annual sediment yield for a stream based on the computed transport capacity and a specified flow duration curve. Most of the output can be displayed graphically and in printed numeric format.
Output format	The program creates a DSS file containing time series data, rating curves, and maximum water-surface elevation profiles.

Table B-11
HEC-FFA Features

Features	Analysis Procedure
Parameter estimation	Estimate parameters with method of moments; this assumes sample mean, standard deviation, skew coefficient = parent population mean, standard deviation, and skew coefficient. To account for variability in skew computed from small samples, use weighted sum of station skew and regional skew.
Outlier	These are observations that "... depart significantly from the trend of the remaining data." Model identifies high and low outliers. If information available indicates that high outlier is maximum in extended time period, it is treated as historical flow. Otherwise, outlier is treated as part of systematic sample. Low outliers are deleted from sample, and conditional probability adjustment is applied.
Zero flows	If the annual maximum flow is zero (or below a specified threshold), the observation is deleted from the sample. The model parameters are estimated with the remainder of the sample. The resulting probability estimates are adjusted to account for the conditional probability of exceeding a specified discharge, given that a nonzero flow occurs.
Historical flood information	If information is available indicating that an observation represents the greatest flow in a period longer than that represented by the sample, model parameters are computed with historically weighted moments.
Broken record	If observations are missing due to "... conditions not related to flood magnitude," different sample segments are analyzed as a single sample with size equal to the sum of the sample sizes.
Expected probability adjustment	The basic procedure prescribed in Bulletin 17B yields a median discharge frequency function. This adjustment is made to the model results "... to incorporate the effects of uncertainty in application of the [frequency] curve." The resulting mean or expected frequency function is appropriate for economic analysis.

Table B-12
Input Required for HEC-FA Program

Input Item	Description
Time series	Sample series of unregulated, annual-maximum flows that are free of climatic trends, representative of constant watershed conditions, and from a common parent population.
Historical data	If historical flow data outside the continuous time series are available, the user must identify these.
Executive specifications	The user may select from among various plotting positions for visually inspecting the goodness--of-fit, and from among various reports and plots of results.
Parameters	HEC-FA estimates the log Pearson type III parameters from sample statistics. The sample statistics are computed from the input series. However, if desired, the user may specify the sample statistics, thus overriding the computation. Further, the user must specify the regional skew coefficient if the weighting scheme of Bulletin 17B is to be used.

a. EAD. The objective of the HEC-EAD (Expected Annual Flood Damage) program (USACE 1989a) is to compute inundation damage and inundation-reduction benefit as described in Chapters 1 and 2 of this manual, thus permitting evaluation of existing flood hazard and of the anticipated accomplishment of proposed damage-reduction measures.

(1) Mathematical models included in the computer model. Average annual damage, also properly called the

expected annual damage, is computed by integrating the cumulative distribution function (cdf) of annual damage. In the simplest application, EAD uses a numerical integration scheme to integrate a user-provided damage-frequency function and reports the results. These computations can be performed for various damage categories for any number of reaches (subdivisions of the floodplain). Damage-frequency functions are not commonly available, but are derived from statistical, fluvial, and economic data or models, as illustrated in Figure 2-1. The functions may represent the existing without-project, existing with-project, future without-project, and/or future with-project state of the floodplain. EAD will perform this manipulation for any alternative conditions defined by the user. The functions shown in Figure 2-1 may change with time. EAD includes the appropriate discounting formulas as required by the Principles and Guidelines to "... convert future monetary values to present values."

(2) Input and output. Table B-13 shows the input required for program EAD. EAD output includes the following: a summary report of the user's input; the derived damage-frequency functions, sorted by reach, for each damage category, plus the aggregate function, for the existing, without-project condition, and for each alternative condition defined by the user; a report of the computed average annual damage, sorted by reach, for each damage category and the aggregate, for the existing, without-project condition and for each alternative condition defined by the user. The inundation-reduction benefit of each with-project condition is displayed also.

(3) Utility programs. The HEC has developed utility programs that simplify use of EAD or provide additional capabilities. The SID program provides data management capabilities for the numerous stage-damage functions typical of a major flood-control study (USACE 1989b). It yields input in the format required for EAD. The FDA package is a complete ensemble of flood-damage analysis models (USACE 1988a). It includes EAD, SID, and utility programs that permit linkage with statistical and fluvial process models through the HEC-DSS.

b. HEC-5. Program HEC-5 models a reservoir or system of reservoirs that are operated to manage excess water (USACE 1982b). Other computer models, including HEC-1, can simulate the operation of a detention structure in which that operation is a function of the properties of the outlet works. HEC-5, however, simulates operation that is a function of both the properties of the outlet works and an operator's specification of the manner in which the reservoirs should function. With HEC-5, storage in each reservoir in a system is divided into zones. Within each zone, the user defines indexed storage levels. The model will simulate operation to meet specified system constraints and to keep system reservoirs in balance, with each at the same index level. System constraints that may be modeled are summarized in Table B-14. In addition to modeling reservoir flood-control operation, HEC-5 includes algorithms for modeling reservoir system operation for conservation purposes.

(1) Mathematical models included in the computer model. HEC-5 includes various models for streamflow routing, including the Muskingum and storage models. It includes also a reservoir storage routing model. For reservoirs with hydroelectric power generation facilities, an energy production model is included.

(2) Input and output. Input required includes the following: reservoir inflows and intermediate-area runoff, reservoir evaporation rates, routing-model parameters, description of the reservoirs and the physical relationships of reservoirs, channel, etc., and a definition of the operating policy. HEC-5 output includes the following: a summary of the user's input; for each reservoir, a summary

Table B-13
Input Required for EAD Program

Input Item	Description
Job specification	User must define discount rate, period of analysis.
Statistical function	User must provide either discharge versus probability, stage versus probability, or damage versus probability function.
Other functions	Depending on the form of the statistical function provided, user must provide other functions necessary to derive a damage versus probability function. These may include stage-damage and/or stage-discharge functions.

Table B-14
HEC-5 Flood-Control Operation Rules

Constraint on Release Made	Condition
Release to draw storage to top of conservation pool without exceeding channel capacity at reservoir or downstream points for which reservoir is operated	Storage is between top of conservation pool and top of flood-control pool
Release equal to or greater than minimum desired flow	Storage greater than top buffer storage
Release equal to minimum required flow	Storage between top inactive and top of buffer pool
No release	Storage below top of inactive pool
Release required to satisfy hydropower requirement	If that release is greater than controlling desired or required flows for above conditions
Release limited to user-specified rate of change	Unless reservoir is in surcharge operation
No release that will contribute to flooding downstream	If flood storage is available
Release to maintain downstream flow at channel capacity	If operating for flood control
Release from reservoir at greatest level	If two or more reservoirs on parallel streams operate for common downstream point
Release to bring upper reservoir to same index level as downstream reservoir	If two reservoirs are in tandem

of inflows, releases, and storage for the period of analysis; for each system control point, a summary of flows for the period of analysis; and if flood-damage relationships are provided, a summary of damage at each location. HEC-5 also includes links to HEC-DSS. Thus flood hydrographs can be computed and filed in the database by a catchment-process model, then retrieved for reservoir-accomplishment analysis with HEC-5.

c. HEC-IFH. HEC's Interior Flood Hydrology program, HEC-IFH, was developed specifically for hydrologic analysis of interior areas—areas protected from direct riverine, lake, or tidal flooding by levees, floodwalls, or seawalls (USACE 1992b). Using either a continuous or event simulation, it will determine stage-frequency and flooding duration within the interior area. The program is described in detail in a user's manual (USACE 1992b).

(1) Mathematical models included. HEC-IFH includes runoff-process, fluvial-process, pressure-flow process, and statistical-process models. The runoff-process and fluvial-process (routing) models are essentially the same as those included in program HEC-1. These are described in paragraph B-2. HEC-IFH includes also a pond-operation model that accounts for discharge by gravity-outlet flow and pumping and a culvert hydraulics model to simulate the outlet behavior.

(2) Input and output.

(a) HEC-IFH is an interactive program: Program functions are user controlled through a set of menus, and user input is provided on data-entry screens. In addition to the input required for runoff and routing computations with program HEC-1, HEC-IFH requires the input shown in Table B-15.

(b) HEC-IFH output includes input summaries; results of simulation, either for the continuous period or for individual events; aggregate time-period performance summaries for continuous simulation; and stage-frequency functions. Most of these results can be presented in tabular or graphical format.

Table B-15
HEC-IFH Input

Input Item	Description
Pond characteristics	Interior-area pond elevation versus area versus volume relationship
Gravity outlet characteristics	Description of maximum 25 outlets, to include type, length, elevations, and gate descriptions
Pump characteristics	Description of maximum 10 pumps, to include total head versus discharge capacity versus efficiency, pump-on and pump-off elevations
Additional hydrologic data	Stage hydrograph for exterior channel, either continuous or for single event. External flow into system, overflow, diversion, seepage